Autonomous Aerobraking Development Plan

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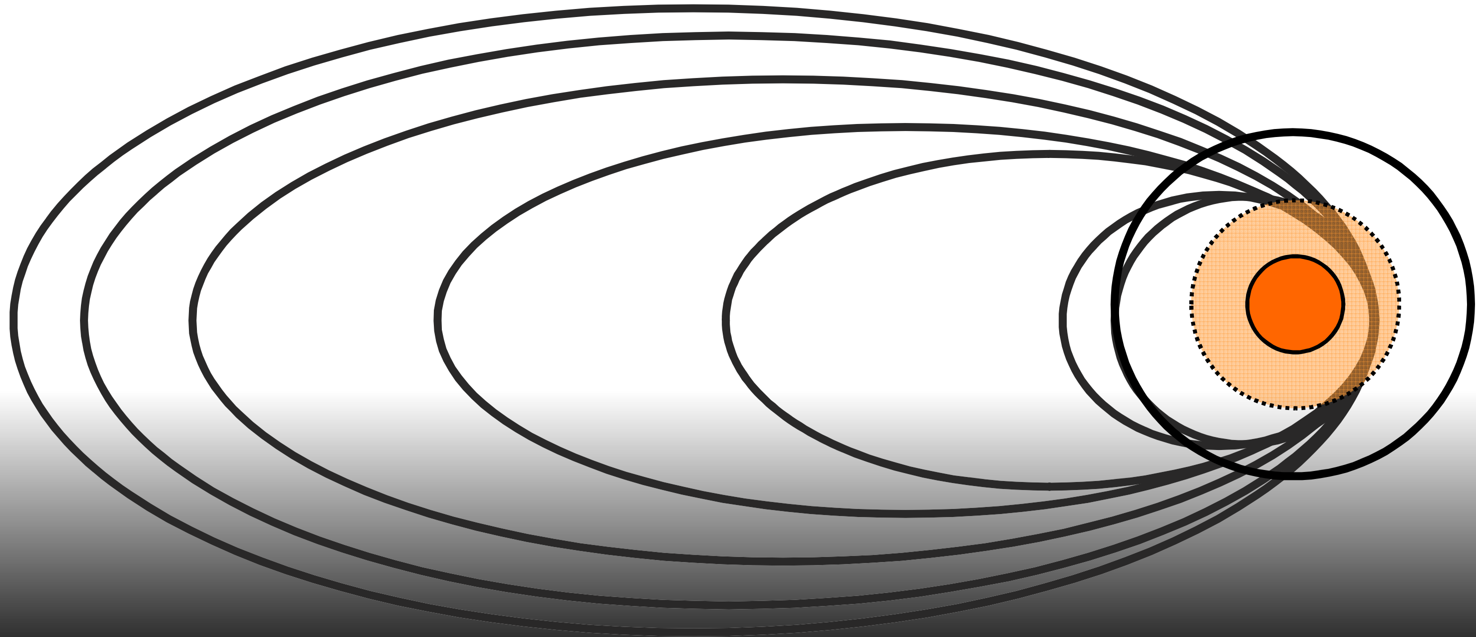
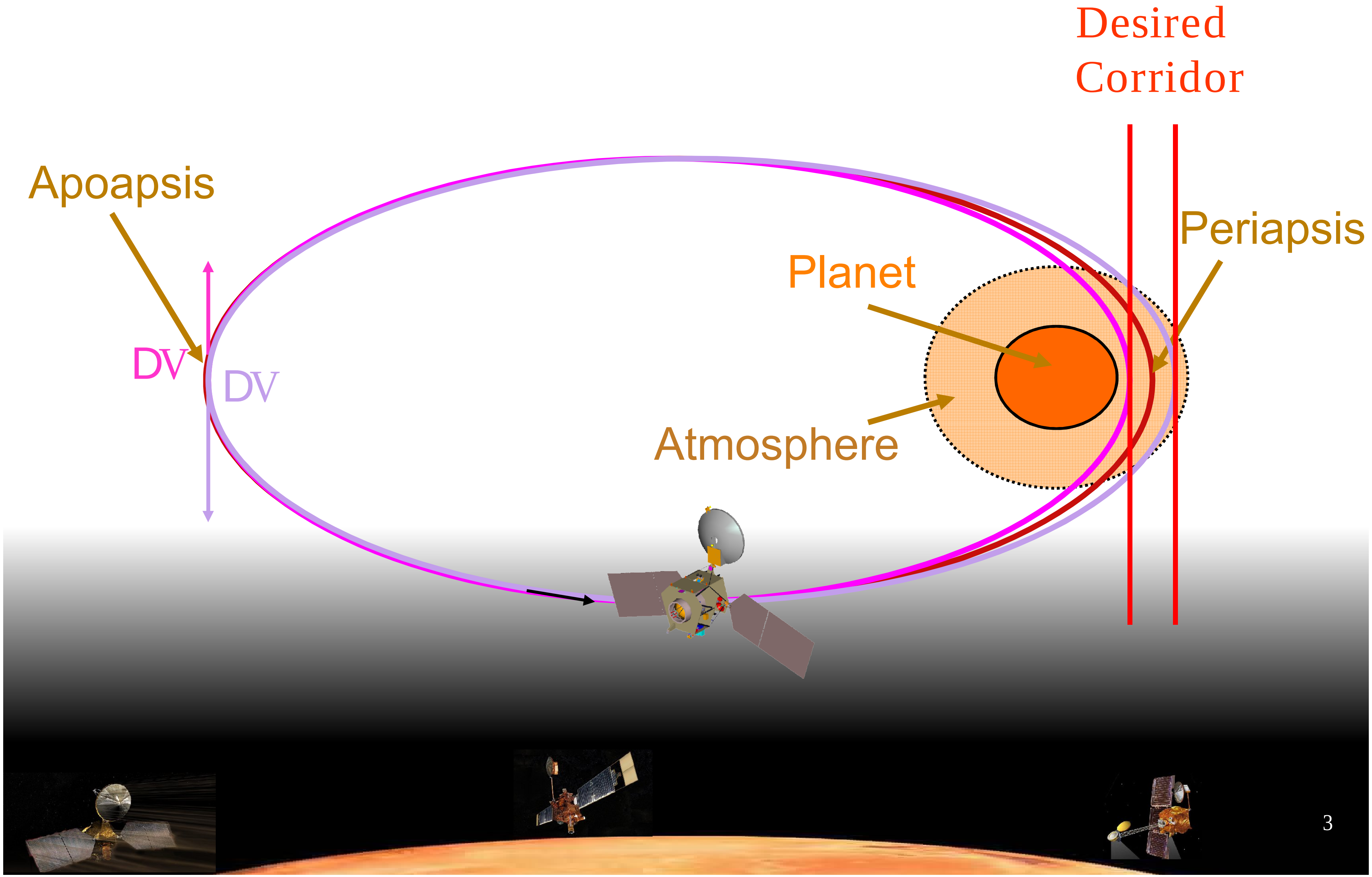
Aerobraking: Removing Orbital Energy

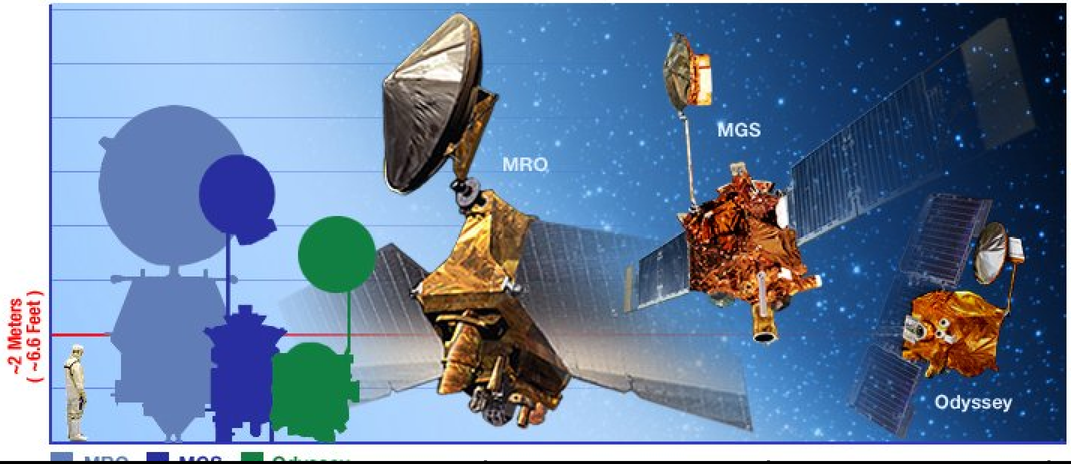
Repeated entry into a planet's atmosphere gradually reduces the spacecraft's periapsis velocity thus reducing its orbit



Aerobraking “Corridor”



Aerobraking Spacecraft Comparison



	Magellan	MGS	Odyssey	MRO
Launch Year	1989	1996	2001	2005
Dry Mass (kg)	1035	677	380	968
AB Orbits	730	886	330	428
AB Days	70	17 months	77	149
AB Period Change (hr)	3.2-1.6	45-1.9	18-2.0	34-1.9
DV Savings (m/s)	1220	1220	1090	1190
Propellant Savings (kg)	490	330	320	580

*reference: Spencer, D and Tolson, R, “Aerobraking Cost and Risk Decisions” Journal of Spacecraft and Rockets. Vol. 44, No. 6, Nov-Dec 007.

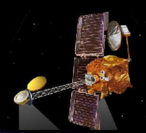
Aerobraking Ops
Main Phase (not walkin or end game)

- Weekly
  - Determine mission strategy for next week
    - Corridor design
    - Determine updates to atmospheric models, aerodynamic models, thermal models, etc.
    - Etc.
- Daily
  - Determine maneuver strategy required to remain within corridor
  - Refine atmospheric model
  - Etc.

What Is Meant by Autonomous Aerobraking

- Moving the **daily** ground activity to the spacecraft
  - Ground would continue to provide the weekly and overall mission strategy
- Spacecraft would calculate its own ephemeris
  - All aerobraking activities are referenced to periapsis and all correction burns are ideally done at apoapsis
- Spacecraft would calculate its own atmospheric model
- Spacecraft would determine the maneuver strategy to remain within the specified corridor
  - Spacecraft would design and execute any required maneuvers
- Note: Odyssey Aerobraking operations costs were $4.8M (FY'02$)*. Autonomy would save approx **$3-5M** in operational costs and **$5.9M** in DSN costs if used for Odyssey

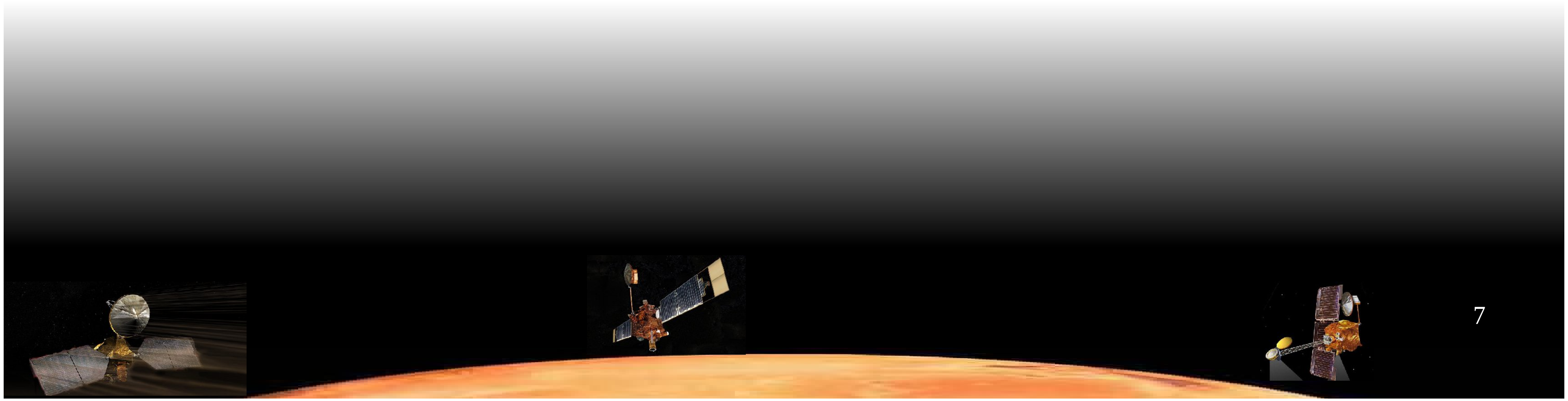
*reference: Spencer, D and Tolson, R, "Aerobraking Cost and Risk Decisions" Journal of Spacecraft and Rockets. Vol. 44, No. 6, Nov-Dec 007.



What is Required for Autonomous Aerobraking (1 of 4)

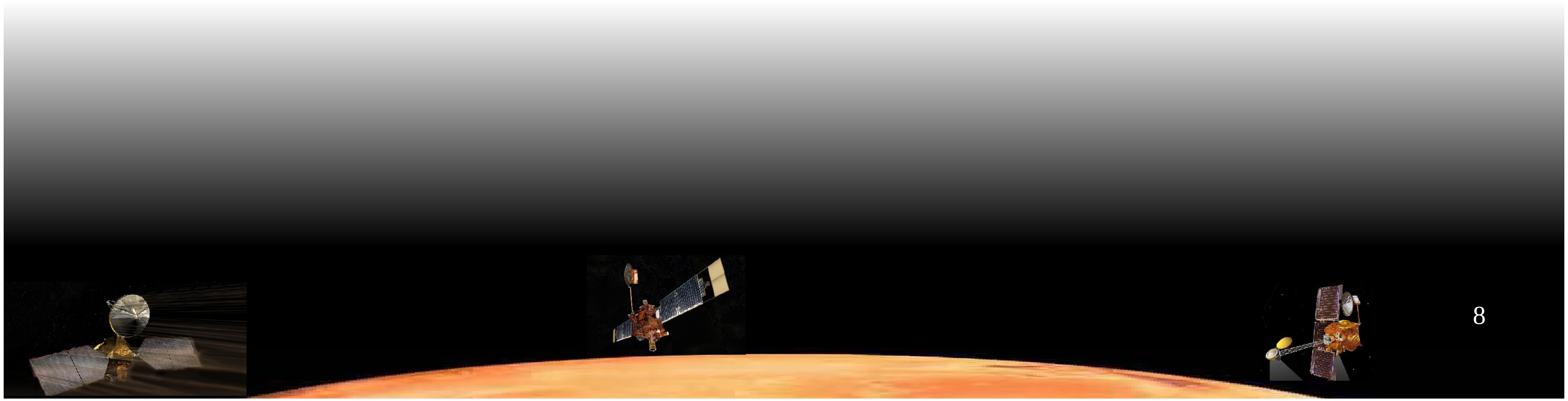
Maneuver planning tool

- Adaptation of tool developed for Odyssey and refined for MRO for mission design and operations
- Used for onboard determination of daily maneuver decisions and execution
- Allows for emergency maneuvers - e.g. If heating rate (or dynamic pressure, or temperature) exceeds x pop out of atmosphere



What is Required for Autonomous Aerobraking (2 of 4)

- On board Ephemeris determination
  - Increase in error in predicting time of periapsis passage requires frequent ephemeris updates from the ground using tracking data from DSN
  - If high quality ephemeris estimation can be done on-board, number of required updates could be reduced (Goal on-board ephemeris would be adequate for aerobraking ops for at least 1 week before requiring ground update)

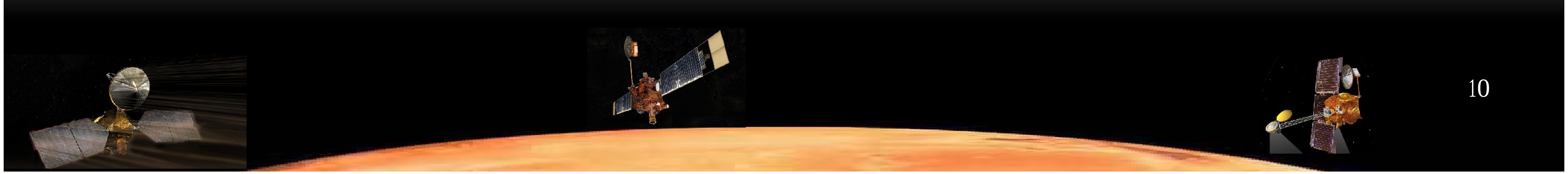


What is Required for Autonomous Aerobraking (3 of 4)

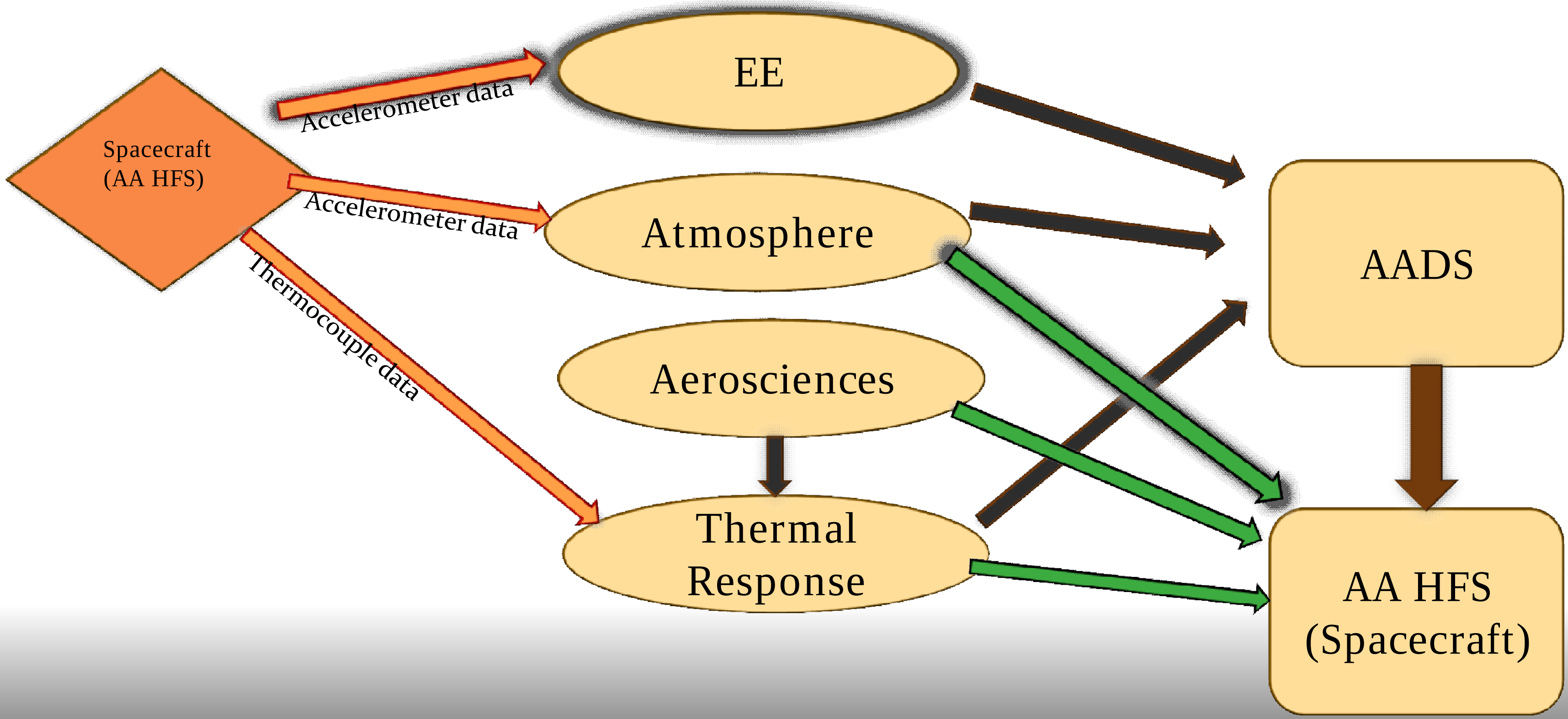
- Demonstrate autonomous aerobraking through use of high fidelity simulation
  - Includes models of all ephemeris determination instrumentation
  - Includes models of all additional instrumentation used in aerobraking (thermocouples)
  - Includes flight-like processor to demonstrate capability to perform all required operations within time allowed
- Peer review to establish that autonomous aerobraking is ready to be included on mission in shadow mode

What is Required for Autonomous Aerobraking (4 of 4)

- Included on AB mission
  - Autonomous AB would operate in shadow (listen – only) mode
  - Ephemeris determined would be compared to ground truth to confirm capability
  - Maneuver decisions compared to ops team
- Peer-review to confirm validity of autonomous AB and any limitations (e.g. collision avoidance)
- Autonomous aerobraking ready for operation on flight mission

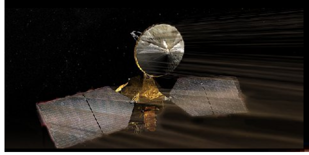


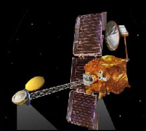
Data/Model Flow



AADS Overview

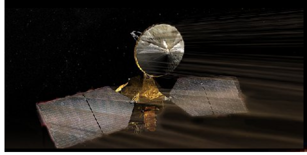
- AADS designed for main phase analysis only (not walk-in or endgame)
- Ephemeris prediction and maneuver calculation performed after atmospheric exit
- Using integrated accelerometer data, ephemeris estimator predicts position of apoapsis and next periapsis
- Atmosphere model estimates atmospheric density and scale height at this next periapsis position
- Thermal response uses density prediction and previous pass’s initial temperature (temp prior to atmospheric pass) to estimate maximum temperature on the solar array at periapsis
- AADS calculates location of spacecraft (temperature, heat rate, or dynamic pressure) within designed corridor. If outside corridor, will calculate direction and magnitude of maneuver to move this next orbit within corridor
- If previous orbit or predicted orbit exceeds flight allowable limit, AADS will return a pop-up maneuver to spacecraft

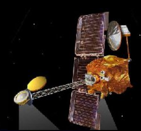




AADS Year 1 Development Plan

- Develop AADS: POST2-derived AA simulation
  - Simplified software
  - Maneuver prediction logic – based on MRO logic
  - Corridor may be defined as heat rate, dynamic pressure, or temperature
  - Pop-up strategy maintained
  - Collision avoidance?
- Incorporate models
  - Ephemeris Estimator
  - Atmospheric Density Estimator
  - Thermal Response
- Test against POST2 full simulation
  - Nominal/Stressing atmosphere
  - POST2 full simulation must be configured for Venus, Titan atmospheres and thermal models
- Deliver AADS to AA HFS
  - Converted to C language
  - Nominal/Stressing atmosphere





AA Testing Plan

- Compare AADS with POST2 – MRO simulation
  - 3 test cases: Long-period, mid-period, short period orbit cases
  - Did we implement correctly?
  - Did AADS compute the same maneuver as POST2?
- Incorporate EE and atmospheric density estimator into POST2
  - Compare ephemeris results from perfect ephemeris (truth) with perfect sensors to EE within AADS
  - Compare results using Mars, Venus, and Titan atmospheres – this tests the EE with various 3rd body perturbations (Saturn, Sun, etc)
- Incorporate AADS, EE and atmospheric density estimator into AA HFS for "truth" testing
- Establish test matrix for Mars – including heat rate indicator boundary, dynamic pressure boundary, and temperature boundary – comparing corridor control relationship
- Stress Test with variable atmospheres (MarsGRAM, ODY, MRO, MGS data) for Mars, expect EE and Mars atmospheres to be modified per our results
- Test, retest with Mars
- Additional testing for Venus, Titan – expect updates.

Development Plan

	Tasks	Phase Product
Phase 1 (Only Funded Phase)	Develop standalone autonomous aerobraking code; develop high fidelity aerobraking simulation; develop autonomous ephemeris estimator – incorporate to stand-alone tool	Autonomous aerobraking feasibility Limitations to autonomous aerobraking
Phase 2	Port autonomous aerobraking modules to flight-like processor; nominal testing	Physical cost of autonomous aerobraking (e.g. is dedicated processor required?)
Phase 3	Additional testing of autonomous aerobraking flight-like simulator	Autonomous aerobraking operability
Phase 4	Incorporation of autonomous aerobraking to flight vehicle	Flight demonstration